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# Costa da Caparica Artificial Sand Nourishment and Coastal Dynamics

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**ABSTRACT**

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Since 1870 important physiographic transformations have occurred on Costa da Caparica. Evidence of such transformations is, for instance, coastline retreat – the noticeable sand spit retreat of about 3 km – which caused an irreversible loss of beach width and dunes. To minimize losses and stabilize the coastline some groins and a seawall were constructed. As a result, the coastline has remained more or less stable for almost 30 years (1972-2000), although with a continuous loss of sand. From 2000 on erosion events increased, especially at S. João beach, with massive sediment removal from the beach and dunes. Several alternative options to minimize coastline retreat and infrastructure destruction were considered, from which emerged one that basically consisted of reshaping the existent groins and seawall with a 3 million $m^3$ sand nourishment. In parallel, a monitoring program was to be implemented. To date, the reshaping works are complete and a total of 1,5 million $m^3$ has been introduced into the systems in two nourishments (0.5 million $m^3$ and 1 million $m^3$, accordingly). From the beginning, a comprehensive monitoring program comprised of several hydrographical and topographical surveys has been implemented. This paper presents a discussion on selected interventions and the construction phases, as well as survey results on the sediment budget. Complementary solutions to sustain the nourished sand on the beach are being considered and are presented in-brief.

**ADITIONAL INDEX WORDS:** *Morphodynamics, rehabilitation, monitoring*

## INTRODUCTION

The coastal stretch between Cova do Vapor – Costa da Caparica, located on southern bank of the Tagus river inlet (Figure 1), started a new cycle of coastline retreat in the winter of 2000/2001 with serious erosion and overwashes on S. João beach and on the fore dune. Several small emergency works were carried out during the 2002/2003 and 2003/2004 winters to minimize storm damage.

Up to 1870 this stretch was protected by a sand spit 3 km in length, connected to the Bugio lighthouse. This sand spit extended towards Bugio until 1929, although some retreat was observed within this period. Between 1929 and 1957 the sand spit retreated about 3 km, and from that period on there was an irreversible loss of sand from the beach and dunes (VELOSO-GOMES *et al.* 2004 and 2006a).

Several coastal protection defences were built up between 1959 and 1963 and 1968-1971 at Cova do Vapor, and between 1959-1971 on the Costa da Caparica waterfront (a seawall 2.5 km long and seven groins, each more than 180m in length). The coastal zone remained more or less stable from 1972 to 2000 despite some localized overtopping events, namely during the winter of 1995-1996 (VELOSO-GOMES *et al.* 2004 and 2006a).

Besides erosion, this area is subjected to significant urban and tourism pressures that cause extra difficulty for coastal zone management. As illustrated in Figure 1, the urban area increased considerably between 1972 and 1996, and there are proposals for new developments.

From a geological perspective this area is composed of alluvium deposits (coastal plain) formed through the interaction of the sea and Tagus river flow regimes. Along the coast ca. 1.5 km from the coastline there is a scarp slope known as the fossil cliff of Costa da Caparica (Figure 1) ca. 70 m in height. This important feature will act as a natural buffer barrier in case of erosion, or in case of sea level rise on a geological scale (VELOSO-GOMES *et al.* 2004).

The Tagus river is the main sediment source, but the sediment supply is very intermittent and correlated with flow variability and wave regime. Important dredging activities occurred in the past at the Lisbon harbour navigation channel and at the NATO navy pier near Cova do Vapor. The amounts and locations of such activities have not been released so far, and this presents a problem in evaluating sediment budgets.

The wave climate in general is characterized by significant wave heights ranging from 0.5 and 2.5 m, with periods ranging from 5 to 15 seconds with higher frequencies and intensities coming from WSW to WNW. Due to natural protection from a cape near the right bank of the river mouth this coastal zone is more exposed to sea storms coming from SW. During these storms significant wave heights can reach 5 m or more (one year return period). There are important local diffraction / refraction phenomena as a result of interaction phenomena between waves, bottom contours and fluvial currents. Several hydrodynamic models have been applied to this coastal area and to the low estuary. From their results and from field observations it can be concluded that refraction and diffraction patterns explain the fact

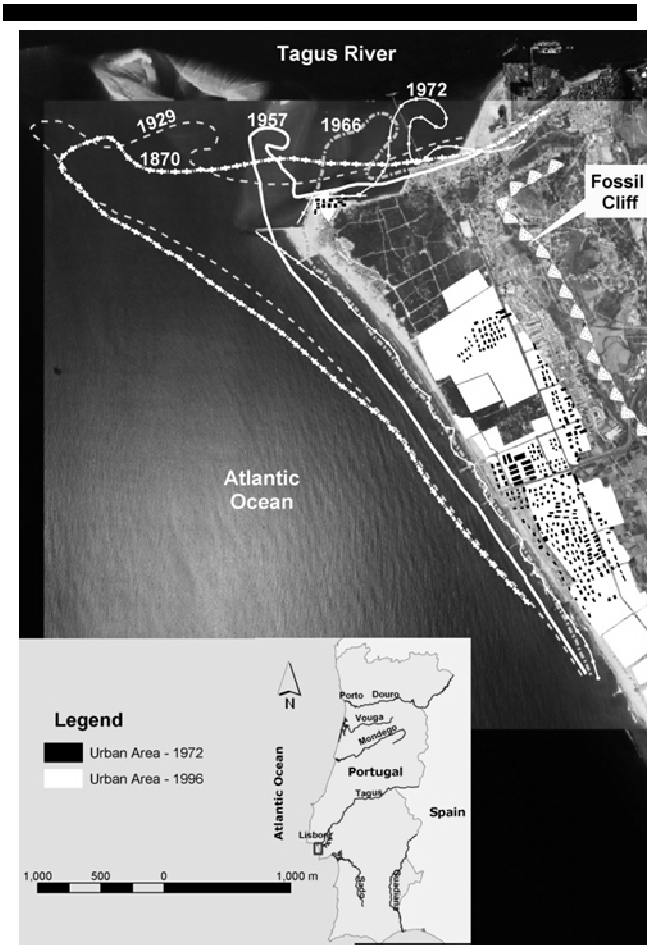


Figure 1. Cova do Vapor – Costa da Caparica coastline and urban area evolution.

that the dominant littoral drift transport near the coastal waterfront is from south to north.

The tidal regime is semidiurnal with a maximum spring tide up to 3.8 m. Meteorological tides during storm surges can reach 0.5 m. In the river mouth, currents at high spring tides can reach more than 2.0 m/s and 1.8 m/s respectively during flood and ebb. The intensity of the tidal currents in front of Costa da Caparica beach is much smaller, reaching up to 0.2 m/s from south to north (OLIVEIRA *et al.,* 1999).

## METHODOLOGY

After the 2000/2001 winter it was understood by coastal management authority that this area was very dynamic and vulnerable and coastal defences were needed for safety reasons, especially during storm events. At that time coastal defence structures presented huge damage and maintenance work, and changes in their design were needed in some cases.

Several structural options to protect the Costa da Caparica were proposed and discussed (VELOSO-GOMES *et al.* 2004, 2006a, 2006b).

**Approved option**

The approved option is being implemented (Figure 2), and was divided into three phases (FEUP/IHRH, 2003, VELOSO-GOMES *et al.,* 2006b):

First Phase – October 2004/May 2005 and October 2005/May 2006:

- Reshaping the existing groins: increasing the length and reconstruction of those that will have a "structural" role and reducing the length of those that could be dismantled in the medium-term.
- Reshaping the existing seawall in the urban waterfront.

Second Phase:

- Artificial sand nourishment of the beaches and dunes, with 3 million $m^3$ of sand dredged from the navigation channel as the source of sediments (0.5 million $m^3$ were nourished in July-September 2007; 1 million $m^3$ in August-November 2008; and another 1 million $m^3$ in 2009). There are two alternative off-shore borrowing areas if the dredging volumes become insufficient.
- Dune rehabilitation and protection where there are no seawalls due to reasons of safety and natural protection.
- Urban seafront rehabilitation (POLIS Program approved in 2005 / 2006).
- Seafront urban development control in the coastal zone south of the groin field (Coastal Master Plan approved in 2003 by the Government after public discussion) due to reasons of safety and natural protection.
- Cova do Vapor settlement retreat (Coastal Master Plan approved in 2003 by the Government after public discussion) due to reasons of safety and landscape.

Third Phase:

- After a minimum of five years monitoring, the third phase intervention will consider the removal of three small groins and increase the length of the remaining ones, as well as further artificial sand nourishments.

**Monitoring**

The monitoring program has three main objectives: to better understand local dynamics and hydro morphology, to clarify the behaviour of the groin field and to assess the artificial sand nourishment life-span.

There is no past experience on the Portuguese west coast concerning nourishment life-spans in highly energetic environments. In this kind of environment it is expected that medium/long term positive effects can only be achieved if new reloads are made periodically. The life-span of the first nourishment program will be very important to improving the cost-benefit analysis.

On the Portuguese northern west coast the potential littoral drift transport by oblique waves can reach up to two million cubic meters per year. Artificial sand nourishment can be an unfeasible solution if there are no transverse structures. This is what happened in Porto (Castelo do Queijo), where a 2 million $m^3$ nourishment project from harbour dredging activities had almost no significant positive impact on the beach.

In the less exposed southern coast of Portugal (Algarve) beach nourishments have been performed with varying degrees of success. When such nourishments are implemented between breakwaters and groins (like in Vilamoura marina) or between breakwaters and natural caps (like in Praia da Rocha, Portimão) they behave quite well with respect to the residence period. On the contrary, when implemented on an open coast (like in Vale do Lobo) the life span can be only about five years.

The monitoring program for Costa da Caparica consists of the following:

- Coastal structures surveys – one annual overall survey to be performed in May, as well as coastal structure inspections after major storms.

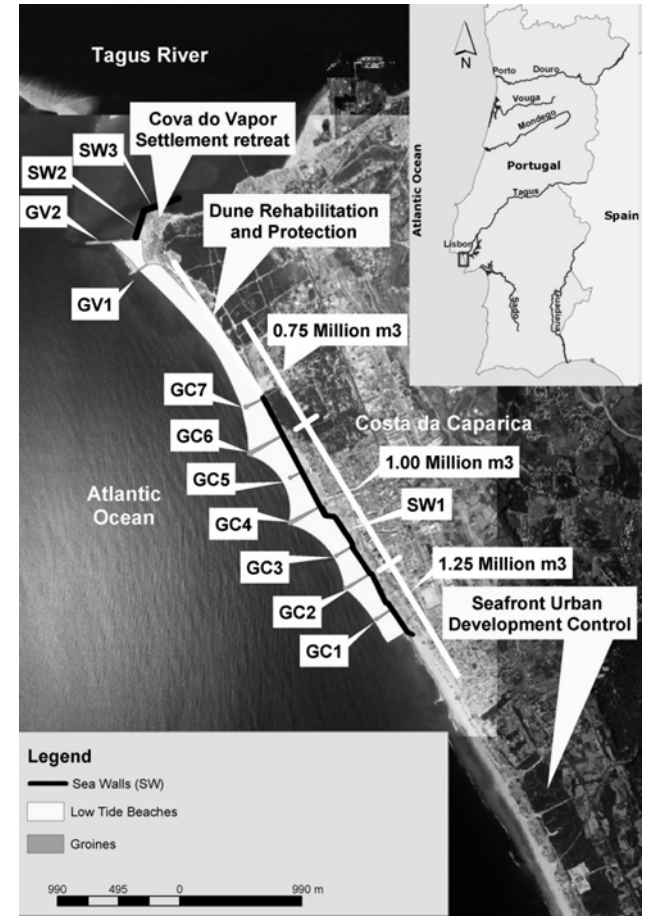


Figure 2. Cova do Vapor – Costa da Caparica, approved intervention.

- Global hydrographic surveys – two annual hydrographic surveys to be performed in May (after the storm season) and September (after the calm season). Complementary surveys immediately before and after artificial nourishment operations.
- Local hydrographic surveys - two annual hydrographic surveys in May and September near the groin heads.
- Aerial image surveys – an annual high-resolution orthogonal photo survey to be done at low spring tide (each year in August/September); oblique photo images before and after artificial nourishment operations.
- Sediment size surveys.

Until now, three structure surveys (September 2001, September 2005 and May 2006), eight global hydrographic surveys (September 2001, September 2005, July 2007, September 2007, December 2007, April 2008, August 2008, November 2008) and two orthogonal and three oblique photographic surveys have been done.

The evaluation of hydrographical surveys before and after beach nourishment operations is of great importance. The first one is taken as an initial reference to adjust technical procedures, and the second one allows quantification of a technical intervention and evaluating/understanding the movement/dynamics of the sand. The sand budget within the system, for different time scales, can be evaluated through the comparison of several surveys.

## RESULTS AND ANALYSIS

The first comparison of bathymetric surveys was done using the surveys from September 2001 and 2005. Due to the limited area covered by the September 2005 survey, the comparison was made only to a part of the Costa da Caparica waterfront, but it can be verified that the smaller depth bathymetric lines are moving landwards. As a consequence, bottom profile steepness increases and higher waves will break closer to the coastline and closer to the coastal structures. Thus the wave energy reaching the coastal structures increases and more sediment is removed from the beach and dunes.

Table 1 illustrates the sediment balance between several surveys carried out since September 2001. The values presented are quantified considering the areas presented in Figure 3. By analysing Table 1 it can be concluded that the solitary source of sediment is artificial, translating into the positive values after artificial sand nourishment. The values that indicate erosion don't seem to be very high, considering the area analysed. However, if the area of analysis is limited to the small strip within the maximum width of groin lengths the values are clearly higher (up to four times higher).

The project considers that after nourishment the final beach profile will be "shaped" by the local wave conditions.

Figure 3 shows data on the artificial sand nourishment interventions carried out so far. The figure in the upper left illustrates sediment balance before (July 2007) and after the first nourishment (September 2007). In this figure a grey area (accretion) can be observed close to the coastal defence structures which indicate where the sediments were placed. In the upper right figure the scenario changes quite considerably. The grey area moves seaward, and close to the coastal defence structures a black area (erosion) is observed. This indicates that the nourished sand is moving towards deeper waters.

In the lowest position, the sediment balance before (August 2008) and after the second nourishment (November 2008) is illustrated. In this figure a grey area (accretion), can be observed close to the coastal defence structures indicating where the sediments were placed.

Other assessments between various surveys have been performed, allowing different time-scale evaluations.

Table 1: Sediment balance from September 2001 to November 2008.

| Area | Surveys | Sediment Balance ($m^3$) |
|---|---|---|
| GV1-GC1 | Sep 2001 – Jul 2007 | ≈-2,000,000 |
| GV1-GC4 | Jul 2007 – Sep 2007* | +495,000 |
| GV1-GC4 | Sep 2007 – Dec 2007 | +28,000 |
| GV1-GC4 | Dec 2007 – Apr 2008 | -102,000 |
| GV1-GC4 | Apr 2008 – Aug 2008 | -20,000 |
| GV1-GC1 | Aug 2008 – Nov 2008** | ≈+1,000,000 |

*After the First Artificial Sand Nourishment

**After the Second Artificial Sand Nourishment


Figure 3. Examples of sediment balance quantifications.

Figure 4. Costa da Caparica sand nourishment (9th October 2008).

## DISCUSSION

The capacity to forecast medium and long-term beach evolution continues to be very limited due to scientific constraints. Apart from this limitation, the inadequacy of field data (namely hydrographic and navigation channel dredging data) it is a shortcoming.

It is necessary to adopt preventive as well as curative policies because of the severity of the present problems. The adopted policy in this urban area is to hold the present coastline.

Hard solutions (coastal defence structures rehabilitation) were combined with soft solutions (artificial sand nourishment, dune protection) and urban planning (urban development control).

The artificial sand nourishment creates a very important buffer zone and through beach enlargement enhances tourism. The urban development has to be contained so the remaining coastal areas and dunes remain vacant.

The beach sand nourishment close to the coastal defence structures (Figure 4) is moving seaward, adjusting the bottom profiles to the local wave climate and tide actions.

Millions of cubic meters of sand have left the system over decades. Based on the sediment balance analysis performed, so far there are no conditions for having a permanent beach in the urban waterfront as happened in the past.

The sand nourishment operations were performed without major conflicts with stakeholders (beach users, surfers, fishermen, camping users, restaurants, anglers) and without personal accidents.

During the last sand nourishment operations an important international water sports event occurred between groins G5, G6 and G7. It was the ISA World Surfing Games 2008, October 11-19, 2008. The contractor changed the planned sequence of operations in order to not interfere with the event.

Key factors for the success achieved has been the overall public perception is that this is a necessary intervention (the maintenance of coastal defences and the artificial nourishment), as well as a continuous dialogue between authorities, the contractor and some of the stakeholders.

It is expected that this joint venture between the coastal management authority and the harbour authority will continue in the future.

The monitoring plan is important to understanding and improving knowledge of the dynamic process in the area, as well as to improve design and maintenance of future coastal protection interventions.

Numerical modelling simulations will benefit from new field data that was inexistent in the past.

Along with the next phase of artificial nourishment, the placement of large sand containers to perform as submerged reefs is being envisaged. The objective is to reduce the transverse movements of sand and hence sustain the nourished sand on the beach.

The management and technical experience gained with this intervention in such a rough environment is very important to dealing with other critical situations that occur in several Portuguese coastal urban areas.

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